NOAA's Coastal Oceanographic Applications and Services of Tides And Lakes (COASTAL) Program

Kristen A. Tronvig
COASTAL Program Manager
National Oceanic and Atmospheric Administration (NOAA)/National Ocean Service (NOS)/
Center for Operational Oceanographic Products and Services (CO-OPS)
1305 East West Highway
Silver Spring, MD 20910-3281, USA
Kristen.Tronvig@noaa.gov

***Abstract*-The National Oceanic and Atmospheric Administration (NOAA)/National Ocean Service (NOS) operates and maintains the National Water Level Program (NWLP) whose backbone is a network of 175 long-term, continuously operating water level stations. Tidal datums derived from these stations have traditionally been important for navigation and shoreline boundary purposes, however there are other beneficial applications and services that water level and datum information can provide. The NOS created its Coastal Oceanographic Applications and Services of Tides And Lakes (COASTAL) Program to focus on such applications. For example, real-time water level information is not only essential for programs supporting safe navigation, such as the Physical Oceanographic Real-Time System (PORTS®), but is also critical for storm surge monitoring for effective evacuation route decision-making efforts. Water level information is also required for successful wetlands restoration projects and for assessing long-term sea level trends. This paper discusses some applications of water level and datum information.**

I. INTRODUCTION

The National Oceanic and Atmospheric Administration (NOAA)/National Ocean Service (NOS)/Center for Operational Oceanographic Products and Services (CO-OPS) operates and maintains the National Water Level Program (NWLP) whose backbone is the National Water Level Observation Network (NWLON). NWLON is a network of 175 long-term, continuously operating water level stations throughout the United States and its island possessions and territories. Tidal datums derived from the data observations collected at these long-term and other shorter-term stations have traditionally been important primarily for navigation and shoreline boundary purposes. For example, water level measurements were needed for charting coastal waters and to fulfill the need to establish a plane of reference, or a datum plane, to which the water level observations and tide prediction tables could be referred. Similarly, soundings taken during hydrographic surveys could also be referred to such a datum. Mean Lower Low Water (MLLW) is NOAA Chart Datum, and Mean High Water (MHW) represents the shoreline on nautical charts [1]. Tidal datums also provide baseline determinations for the Exclusive Economic Zone (EEZ), Territorial Sea and Contiguous Zone, as well as boundaries between private, state, and federal ownership and jurisdiction (Fig. 1).

There are several other beneficial applications and services that water level and datum information can provide. In order to focus on these other, non-navigation applications, CO-OPS recently created its Coastal Oceanographic Applications and Services of Tides And Lakes (COASTAL) Program. Some of these additional uses and requirements include beneficial use of dredged material, coastal planning projects, marsh restoration projects, long-term sea level assessments, storm surge monitoring, evacuation route decision-making, and emergency preparedness. Through its COASTAL Program, CO-OPS often partners with other NOAA offices and other Federal agencies, state and local governments, and non-profit organizations. For most of these projects, additional water level stations are installed, tidal datums are computed and water level analyses are conducted. The applications of tide and water level information to these projects are critical to their success in protecting life, saving property, restoring the environment, and maintaining the economic vitality of the nation. This paper uses examples from existing projects to highlight some of these various applications.

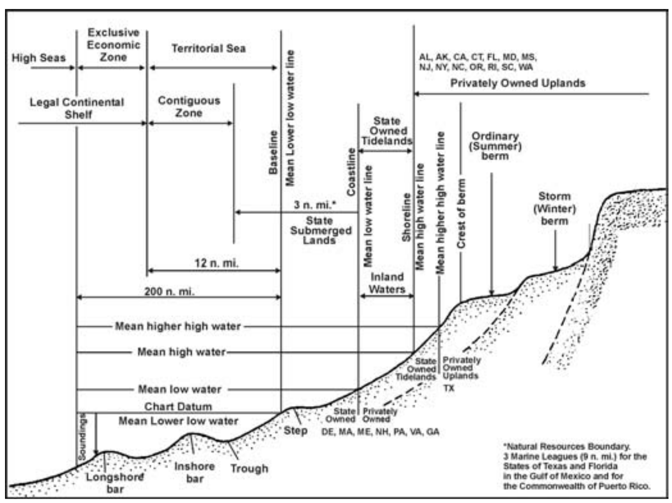

Fig. 1. Tidal datums and their traditional applications.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **01 SEP 2003**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**
4. TITLE AND SUBTITLE **NOAAs Coastal Oceanographic Applications and Services of Tides And Lakes (COASTAL) Program**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **National Oceanic and Atmospheric Administration (NOAA)/National Ocean Service (NOS)/ Center for Operational Oceanographic Products and Services (CO-OPS) 1305 East West Highway Silver Spring, MD 20910-3281, USA**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002146. Oceans 2003 MTS/IEEE Conference, held in San Diego, California on September 22-26, 2003. U.S. Government or Federal Purpose Rights License., The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

II. MARSH RESTORATION

Coastal areas have intrinsic economic, cultural, and aesthetic value. Specifically, wetlands play a crucial role in the productivity of coastal waters, biogeochemical cycling, and geomorphological stability. They act as nurseries for fish and crustaceans and feeding grounds for birds; they store pollutants and nutrients; and they serve as buffer zones to flood events and wave action. However, these fragile ecosystems have been degraded and destroyed over the centuries at amazing rates. The United States has lost over half of its wetlands since the late 18th century. An average of 60,000 acres of wetlands have been lost nationally each year between 1986 and 1997. Coastal wetland loss is caused by both anthropogenic use (such as human population growth and coastal development) as well as natural phenomena (such as sea level change and erosion from coastal storms) [2], [3]. With habitat destruction and the natural systems that estuaries support failing, coastal habitat restoration is becoming a national priority [4]. Thus, it is essential that restoration projects are designed and engineered properly, and subsequently monitored. Wetland vegetation is sensitive to the frequency and duration that it is inundated, suggesting that understanding the hydrodynamics of the system is essential. This critical need for accurate water level information and vertical datums to successfully restore and sustain healthy wetland ecosystems helped shape CO-OPS' COASTAL Program, which grew from a former Marsh Restoration Program.

There are three categories of water level analyses that are conducted for each marsh restoration project under the COASTAL Program: 1) local tidal datums are computed; 2) long-term sea level change is assessed; and 3) frequency and duration of inundation analyses are computed. First, tidal datum elevations are determined relative to present and future marsh surfaces by establishing a water level station (typically, for one year to capture seasonal effects) with local bench marks. Fig. 2 [5] shows a generic marsh restoration study site. The tidal datums are then referenced to specific 19-year National Tidal Datum Epochs (NTDEs) [6], [7]. The most recent NTDE of 1983-2001 was implemented in April 2003 to reflect the latest variations in Mean Sea Level (MSL) along the nation's coasts. The tidal datums are then further linked to a geodetic benchmark network using Global Positioning System (GPS) and/or leveling techniques, thus referencing them to geodetic datums, such as the North American Vertical Datum of 1988 (NAVD88). Kinematic GPS (KGPS) surveys of the marsh topography can also be made. This connection enables Digital Elevation Models (DEMs) to be generated, displaying the different datum elevation relationships. DEMs of tidal and geodetic datum (specifically, MHW and NAVD88, respectively) relationships are beneficial in the planning and construction phases of marsh restoration efforts because they provide baseline information.

Secondly, long-term sea level change, trends and variations are assessed and analyzed to ensure that any sea level rise is appropriately considered in the extended planning phases.

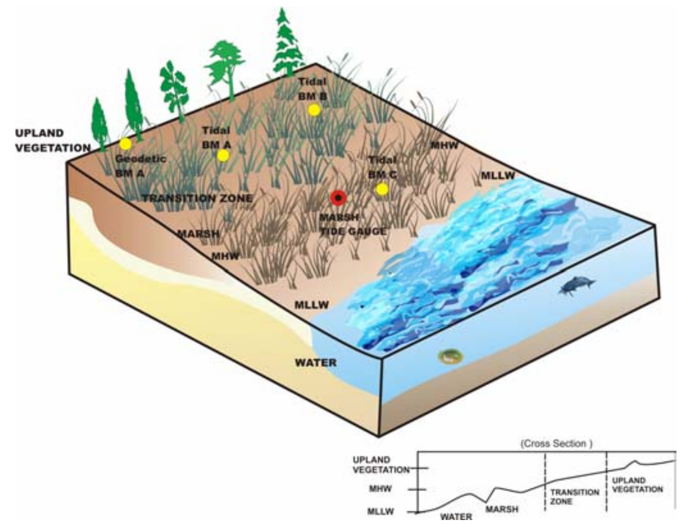

Fig. 2. Schematic of a generic marsh restoration site. It includes a tide station (typically a one-year tide station), local tidal benchmarks, geodetic benchmarks, and delineates vegetation elevation zones, and tidal datum elevations.

Also, long-term viability of functioning marshes is dependent upon proper accretion rates and sediment accumulation in response to local sea level rise [8]. By conducting simultaneous comparisons of the high waters between the short-term station at the marsh and the nearby, long-term NWLON control station, the same long-term sea level trends can be expected at the marsh. Seasonal effects are determined and extrapolated in a similar manner.

Finally, frequency and duration of inundation analyses of the high waters are performed because marsh vegetation is sensitive to how long and how often it is inundated. This information is used to determine where to appropriately plant the different vegetative species.

A. *Fort McHenry, Chesapeake Bay: Wetlands Construction*

In the past two decades, creation and restoration of tidal wetlands has become a required form of mitigation, including many areas in the Chesapeake Bay, such as the wetlands adjacent to the Fort McHenry National Historic Monument and Shrine. These wetlands were originally constructed in 1982 using dredged materials from the excavation of the Fort McHenry Interstate 95 tunnels. They are now being reconstructed from mitigation credits for a new, nearby port slip that will allow more containers to be offloaded.

The intent of this restoration project is to improve the ecological function of the Ft. McHenry tidal wetlands mitigation site through hydrologic modifications and continued maintenance and monitoring of the site. Currently, the functionality of these wetlands is compromised by poor tidal exchange and infiltration of invasive species and trash. Originally, there were three small culverts through the riprap encircling the wetlands, which allowed tidal exchange with

adjacent harbor waters. The culverts have since mostly silted in, largely cutting off tidal exchange and resulting in the degradation of natural salt marsh function at the site. Modifications are being planned to promote regular, natural tidal flooding to the site, control debris accumulation, and enhance its habitat value to plant and animal species. These modifications will have direct benefits to the proportion of the site that is either converted to new aquatic habitat or re-vegetated with native marsh vegetation.

There are many aspects to consider when creating salt marshes within the Chesapeake Bay [9]. Among these considerations for design and construction is the knowledge of the elevation and gradient of the substrate relative to high water datums and mean sea level. Information on the time varying nature of inundation and drying is also required. The physiographic range of the associated species of vegetation is generally related to the elevation of MHW for use in guidance of where to plant. Other considerations include how often marsh surfaces are irregularly flooded due to storm tides and maximum astronomical tides. NOS is working with the National Aquarium in Baltimore (NAIB), Maryland Port Administration (MPA), and MPA engineer consultants with these efforts to ensure that the restoration of the Fort McHenry Wetlands are successful.

NOS/National Geodetic Survey (NGS) has conducted KGPS surveys of the site to obtain existing elevations and has completed a preliminary DEM (Fig. 3). CO-OPS has performed high water analyses and long-term sea level assessments on data from its NWLON station at Fort McHenry, Baltimore, which dates back to 1902 (The Fort McHenry wetlands are very close to that NWLON station, which is located on a U.S. Army Corps of Engineers pier just north of the Fort and the wetlands. Given this proximity, the tidal characteristics, tidal analyses, and tidal datums can be transferred directly to the marsh from the observations at this long-term station.). This combined information was provided in an NOS Report to MPA's engineering consultants and was used to design construction plans for the new wetlands site (Fig. 4).

CO-OPS has also conducted frequency and duration of inundation analyses of the high waters from the NWLON station at Fort McHenry, Baltimore. NAIB biologists will use this information to determine where and when to plant different marsh vegetation. A plot of the duration of inundation for the calendar year 1999 can be seen in Fig. 5. Using the 6-minute interval data before and after the time of each high water, the duration of inundation, or the elapsed time that the water elevation was at or above NAVD88 for each high water, was estimated. Fig. 5 reveals a tiered effect of the duration of inundation dependence on the elevation of the high waters. A distinct tier from the elevation of NAVD88 up to 1.6 feet above NAVD88 (duration of 13 - 14 hours) is readily apparent. There is also a distinct second tier of durations near 20 hours for elevations from 0.6 feet to 1.9 feet above NAVD88. Less defined tiers are found around 35 and 45 hours. There were some extremely long durations of nearly 90 hours on three occasions in the year. This tiered effect is attributed to the effects of weather on the water levels of the upper Chesapeake Bay for extended time periods greater than one day.

Fig. 3. Fort McHenry pre-construction Digital Elevation Model (DEM).

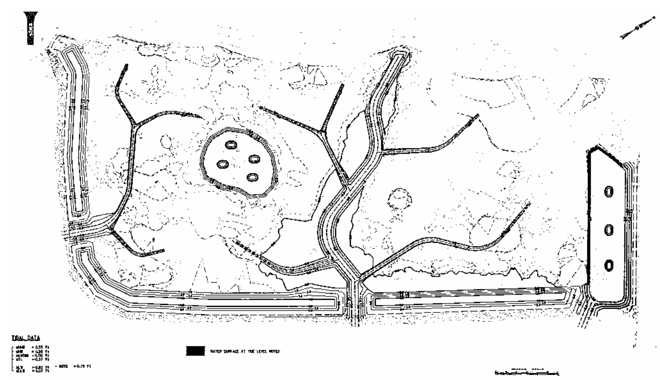

Fig. 4. Fort McHenry new construction design shown at Mean Higher High Water (MHHW).

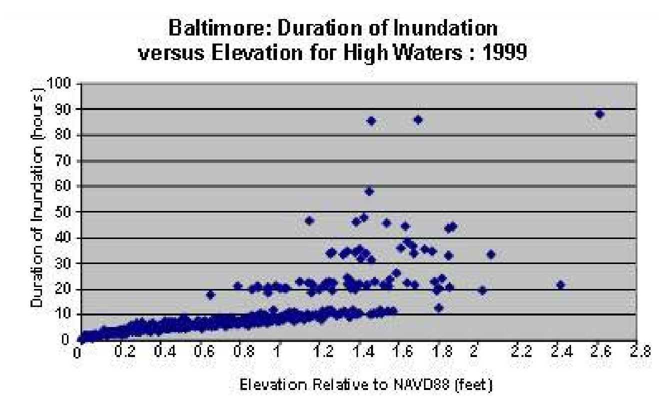

Fig. 5. Duration of inundation curve for Fort McHenry from NWLON station at Baltimore, MD.

B. Qwuloolt, Ebey Slough, Marysville, WA: Breaching Levees

The Qwuloolt Marsh restoration project along the Ebey Slough in Marysville, WA involves restoring about 350 acres of farmland back to wetlands. The project is called Qwuloolt meaning, “Great Marsh” in the Salish Language, the language of the Tulalip Tribe. Ebey Slough is a part of the Snohomish River delta and is tidally influenced by Puget Sound. The site is protected by levees and has been since the early 1900's, most recently for grazing cattle (for a dairy farm) and before that for farming hay. NOAA purchased the property with restoration of the area in mind using funding from litigation due to pollution of the slough from a landfill 2 miles west 20 years ago. The original intent was to breach the levees and flood the property, thus recreating wetland and marsh habitat, without flooding surrounding houses and developments.

CO-OPS installed a water level station at the site for a year and a half. It remained installed and operating for an extra six months so that the effects of a second winter season could captured since the first winter was anomalously dry. The U.S. Army Corps of Engineers (USACE) Seattle District performed the detailed hydrologic and hydraulic studies to support the project [10]. CO-OPS contributed hydrologic data and analyses to the study. The USACE used the tidal and geodetic datum relationships, as well as various analyses that CO-OPS generated for conducting technical hydrologic and hydraulic analyses and design work. These assisted with the model generation of the marsh and were outlined in a USACE feasibility study. For example, Fig. 6 shows the existing elevations of the site. There are three critical elevation contours all relative to NAVD88: 4 ft in green (the marsh surface), 8 ft in blue, and 12 ft in red (the existing levees). A development exists in the northwest corner between the 8 ft and 12 ft elevations, and a new development is being built on the east side just bordering the 12 ft levee. One-year (January through December 2001) tidal datums were computed on the recent NTDE (1983-2001). The MHW elevation is 8.3 ft relative to NAVD88, suggesting that if the levees were breached, the marsh surface would be a pond and the existing developments in the northwest corner would be flooded. Also, the highest tide based on comparisons with the NWLON station at Seattle is estimated at 12.3 ft relative to NAVD88, suggesting that during a coastal storm event, such as a storm event during the 1983 El Niño, the new developments on the western border of the site would also be flooded. This tidal information was critical. All options described in the USACE feasibility study showed that levees needed to be built up higher in areas to prevent the neighboring developments from being flooded.

III. EMERGENCY PREPAREDNESS

During coastal storms, water levels can rise to excessive flood levels. It is useful to know and predict how high these water levels reach. This kind of storm surge information is critical for emergency preparedness purposes for most regions.

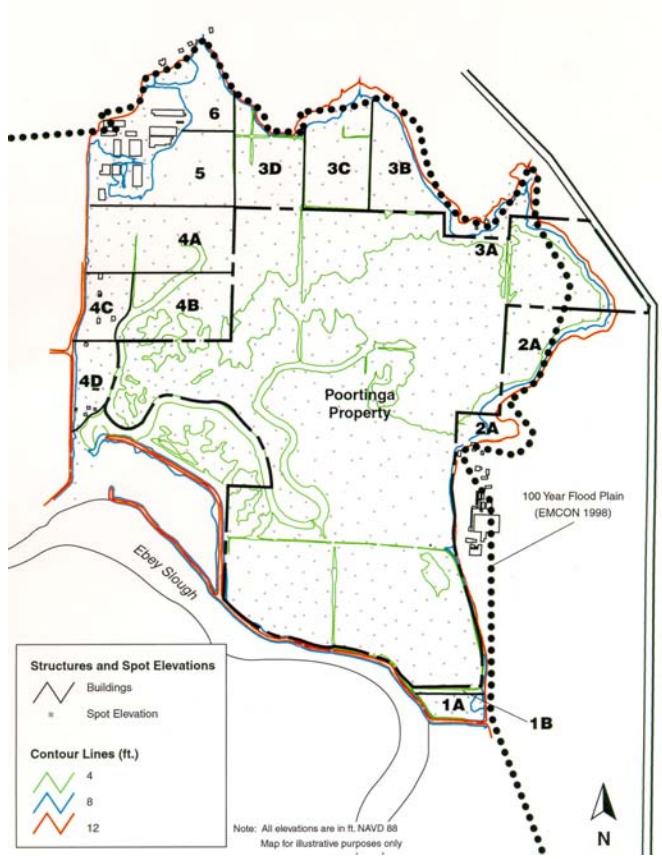

Fig. 6. Existing elevations at Qwuloolt Marsh site in Marysville, WA. Critical elevations are 4 ft, 8 ft, and 12 ft relative to NAVD88.

The State of Louisiana is in extreme need of this information as it is highly susceptible to natural hazards, such as land subsidence and relative sea level rise, hurricanes and other severe storms, and storm surge flooding. Louisiana is also suffering from enormous amounts of coastal land loss, as much as 35 square miles per year, which is an equivalent of 2.55 acres per hour. This coastal land loss is due to land subsidence, sea level rise, shoreline erosion from increased wave action from coastal storms and hurricanes, lack of sedimentation, saltwater intrusion into wetlands, and eutrophication. From a public safety standpoint, subsidence has also lowered evacuation roads along the coast to levels that concern citizens and emergency preparedness officials. Coastal communities, industries and the environment are all negatively affected by the large amounts of coastal land loss in Louisiana. Eighteen percent of the Nation’s oil is produced in coastal Louisiana. The loss of coastal land in Louisiana threatens 30,000 oil wells and their associated infrastructure. Decadal sea level records from tide gauge data are needed to quantify rates of subsidence [11].

There are only two NWLON stations operating along the coast of Louisiana, at Grand Isle and SW Pass, and until recently, these were the only two long-term stations in the State. This deficiency has contributed to an obvious gap in

water level information. The only station with a long-term sea level record is at Grand Isle where the sea level trend is estimated to be 9.85 mm/yr (Fig. 7). However, the sea level trends in Louisiana and how they change geographically along the coast is not known.

A. St. Charles Parish Water Level Monitoring System

An example of a COASTAL Program project that falls under the category of emergency preparedness is the St. Charles Parish Water Level Monitoring System, which was established through a partnership between CO-OPS and St. Charles Parish, LA. This real-time water level monitoring system will provide critical information for saving lives, protecting property, and restoring the environment in this Louisiana community.

The real-time system consists of two new real-time tide and water level stations - one in Lake Pontchartrain in Norco at Bayou LaBranche and one in Lake Salvador at Bayou Gauche - and two existing NWLON stations in Louisiana at Grand Isle and SW Pass. These two new stations will supplement the NWLON. The data from all four water level stations, including meteorological data, are displayed on a local Data Acquisition System in the Parish Emergency Operations Center located in the Hahnville Courthouse across from the Parish government offices. A sample plot of water level data for Norco, Bayou LaBranche is shown in Fig. 8. Emergency managers are able to monitor the data to assess storm surge flooding and use them for evacuation route decision-making, opening and closing water control structures, and public warnings. Residents of St. Charles Parish and neighboring parishes can access the data in real-time over the Internet (http://tidesonline.nos.noaa.gov/) and via telephone (1-866-557-6787). These data are also being fed directly into NOAA's National Weather Service to help improve storm surge and other modeling efforts. The system was established in time for the 2003 hurricane season.

The data will also be beneficial for sea level rise assessments and coastal restoration. In particular, the Norco, Bayou LaBranche station will be instrumental in modeling efforts for the restoration of the LaBranche Wetlands.

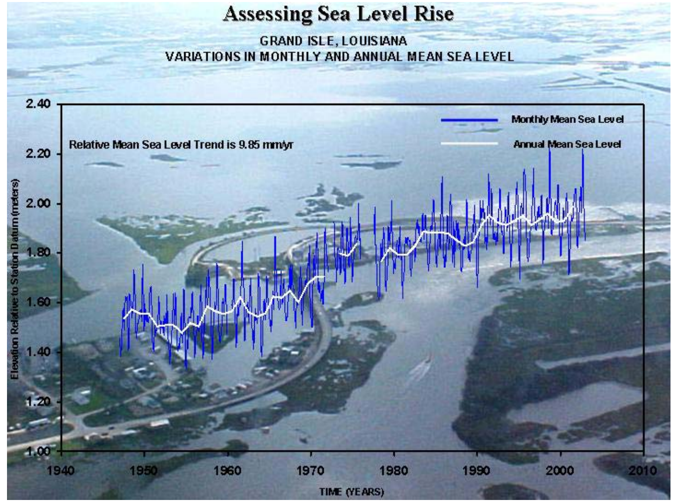

Fig. 7. Long-term (since 1947) relative sea level curve for Grand Isle, LA. Sea level rise is approximately 9.85 mm/yr at Grand Isle. The blue curve shows monthly mean sea level values and the white curve shows the annual mean sea level values. The photo shows the Leeville Bridge on LA-1, which is the main evacuation route for Grand Isle.

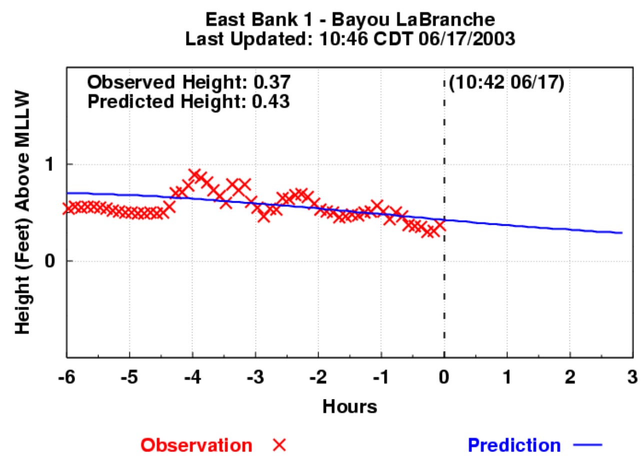

Fig. 8. Example of real-time water level data at Bayou LaBranche, Lake Pontchartrain, LA displayed in the St. Charles Parish Emergency Operations Center. The data are part of the overall St. Charles Parish Water Level Monitoring System. Real-time data are updated every six minutes. The predicted curve is shown in blue and the observed values are shown in red.

IV. NEW APPLICATIONS FOR REMOTE SENSING

A. High Resolution Remote Sensing Data

The Remote Sensing Division (RSD) of NGS is tasked with delineating the shoreline of the United States. NGS has developed various techniques for shoreline compilation through the years that have changed with the introduction of new equipment and techniques, however in each technique (new or old) must be tide-controlled (tide-coordinated). An example of this is the ongoing research in the San Francisco area to test the feasibility of using airborne LIght Detection and Ranging (LIDAR) and the VDatum transformation tool for shoreline mapping [12]. The VDatum tool allows for the seamless transformation between 27 different vertical reference datums.

The method used today by RSD to delineate the shoreline is stereo photogrammetry using tide-coordinated aerial photography controlled by KGPS techniques. Technological advancements in geodetic positioning and airborne remote sensing have led RSD to explore new methods of shoreline mapping, such as the tide-coordinated LIDAR datasets collected at Seal Rocks, the San Francisco study site (Fig. 9). Tide-coordinated aerial photography was also collected to coincide with the MHW flight, along with photo-identifiable ground GPS control. The purpose of the experiment is to quantitatively compare LIDAR-derived shoreline using VDatum with shoreline compiled using traditional photogrammetric techniques. These high resolution remote

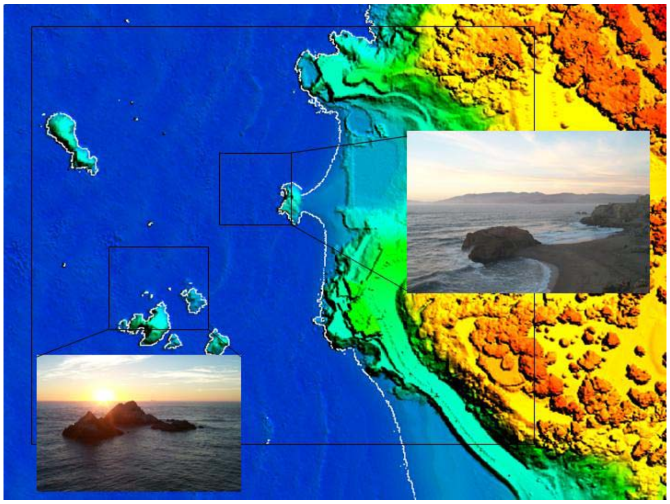

Fig. 9. Seal Rocks (San Francisco), CA. High resolution remote sensing data using LIght Detection And Ranging (LIDAR).

sensing data will be useful for more than just delineating shoreline (MHW) onto nautical charts. The next step is to generate a DEM so that various stages of the tide and different inundation levels can be overlaid on it, thereby providing coastal zone managers with a visual representation of the data so that better decisions can be made.

V. CONCLUSION

From the traditional tide and water level products, new analyses of high waters, and recent technological advancements, more applications of water levels will continue to emerge. This paper shows a snapshot of the types of applications that exist and are being explored and utilized through the COASTAL Program. The Program is young and has already expanded significantly with nearly a dozen different projects and several new partnerships. It is reasonable to expect that the Program will continue to grow through additional partnerships, enhancing the existing partnerships and encouraging an exchange of information. The ultimate goal is to provide improved products and services for the coastal zone customer.

REFERENCES

[1] NOAA (2001). Tidal Datums and Their Applications. Special Publication No. CO-OPS 1. National Oceanic and Atmospheric Administration, Silver Spring, MD - USA.

[2] NOAA (2001). Tidal Datums and Their Applications. Special Publication No. CO-OPS 1. National Oceanic and Atmospheric Administration, Silver Spring, MD - USA.

[3] Douglas, B.C., M.S. Kearney, and S.P. Leatherman (2001). Sea Level Rise, History and Consequences. Academic Press. San Diego, CA-USA, pp. 181-220.

[4] NOAA and Restore America’s Estuaries (2001). A National Strategy to Restore Coastal and Estuarine Habitat, Executive Summary. National Oceanic and Atmospheric Administration, Washington, DC - USA and Restore America’s Estuaries, Arlington, VA - USA.

[5] NOAA (1980). The Relationship Between the Upper Limit of Coastal Wetlands and Tidal Datums along the Pacific Coasts. Report submitted to the Environmental Protection Agency. February 1980. National Oceanic and Atmospheric Administration, Silver Spring, MD-USA.

[6] NOAA (2001). Tidal Datums and Their Applications. Special Publication No. CO-OPS 1. National Oceanic and Atmospheric Administration, Silver Spring, MD – USA, pp. 37-38.

[7] Marmer, H.A. (1951). Tidal Datum Planes. Special Publication No. 135 Revised (1951) Edition. U.S. Department of Commerce/Coast and Geodetic Survey. Washington, DC, USA, pp. 63-64.

[8] Stevenson, J.C. et al. 1989. Marsh and Mangrove Responses to Changes in Sea Level and Sediment Inputs, *Estuaries*, Dedicated Issue, Vol. 12, No. 4, December 1989.

[9] Perry, J.P. et al. 2001. Creating Tidal Salt Marshes in the Chesapeake Bay. *Journal of Coastal Research*, Special Issue NO. 27, Winter 2001.

[10] U.S. Army Corps of Engineers (2001). Qwuloolt/Portinga Technical Report. Prepared for Tulalip Tribes of Washington. Draft Document December 7, 2001. U.S. Army Corps of Engineers Seattle District, Seattle, WA, USA.

[11] Boesch, Donald F., Douglas Levin, Dag Nummedal, and Kevin Bowles. August 1983. Subsidence in Coastal Louisiana: Causes, Rates, and Effects on Wetlands. National Coastal Ecosystems Team, Division of Biological Services, Fish and Wildlife Service. FWS/OBS-83/26.

[12] Parker, Bruce, Dennis Milbert, Kurt Hess, and Stephen Gill. National VDatum – The Implementation of a National Vertical Datum Transformation Database. U.S. Hydrographic Conference 2003 Proceedings/Technical Papers.